NASA-Ames Research Center … *in Silicon Valley*

Hardware Requirements for Biotechnology in Space

Synthetic Biology Workshop

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During the next 50 years…

- ✓ We will travel to the Moon and Mars
- ✓ We will travel to asteroids
- ✓ We will use ***Synthetic Biology*** to revolutionize our approach to sustaining life in space, and defining our purpose there

The Past:

We took familiar biological organisms into space, and engineered environments to suit them.

The Future:

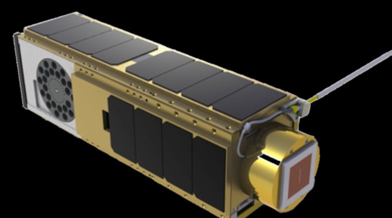
We will engineer biological systems to make them suited to extraterrestrial environments, and employ these systems in new kinds of missions

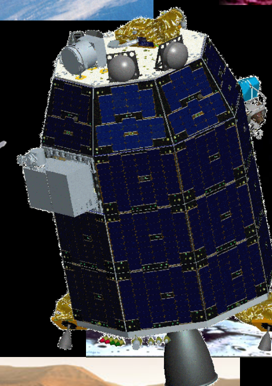
NASA Synthetic Biology Initiative

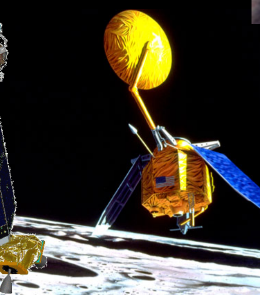
Vision: To harness biology in reliable, robust, engineered systems to support NASA's exploration and science missions, to improve life on Earth, and to help shape NASA's future

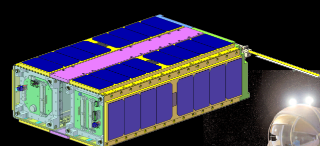
The Space Environment

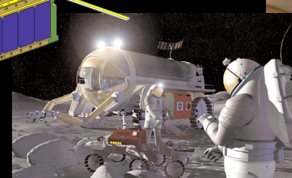
- ISS
- Free Flyers
- Asteroids
- Moon
- Mars
- Beyond

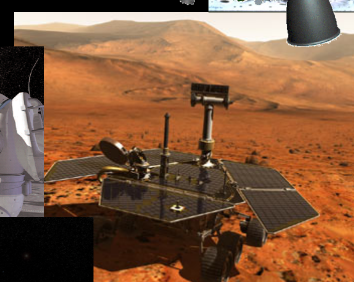


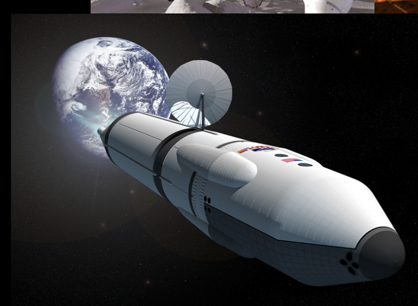


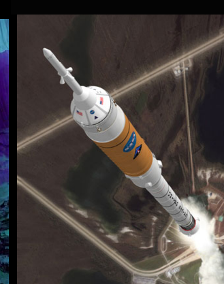


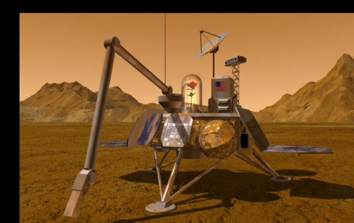




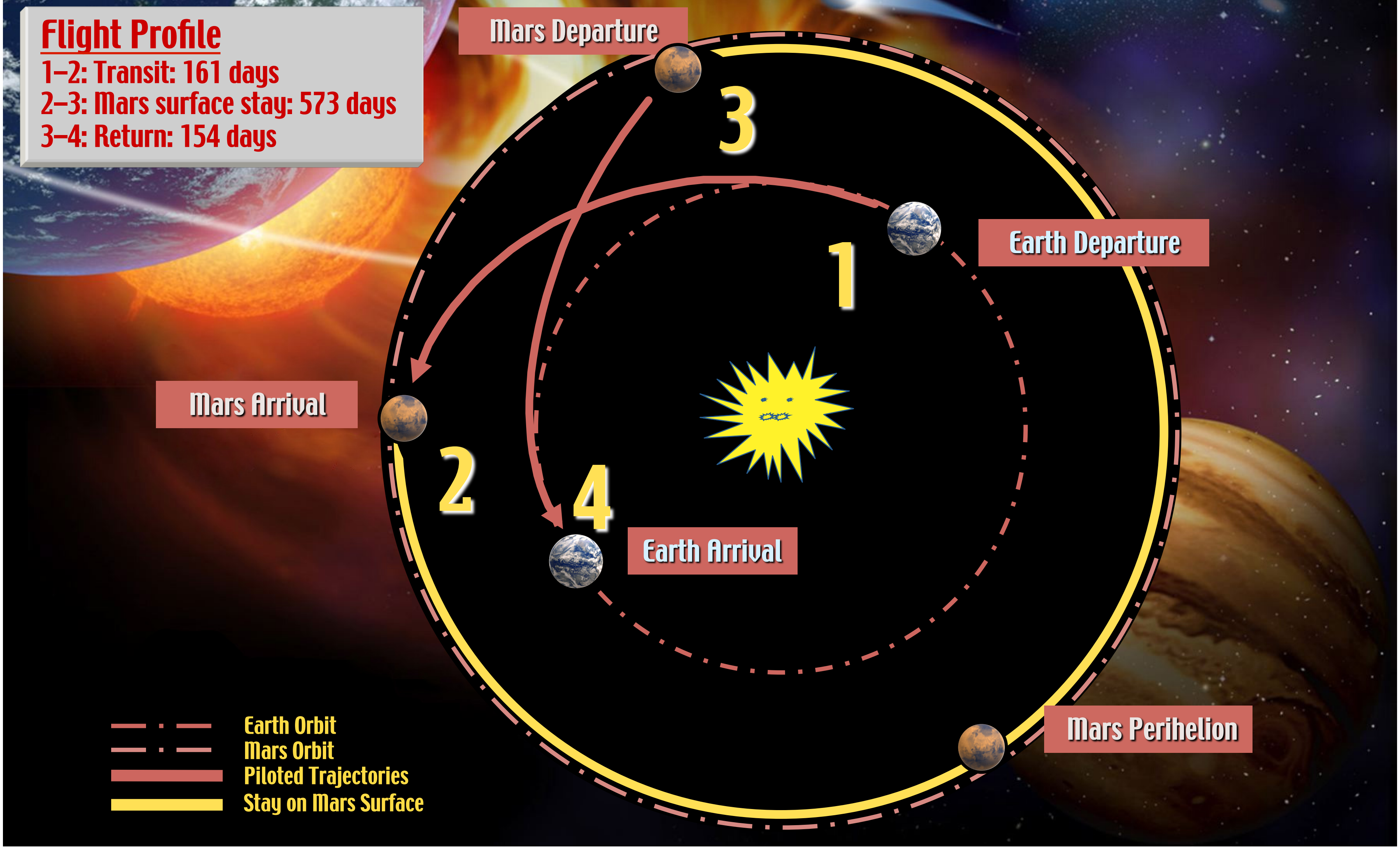








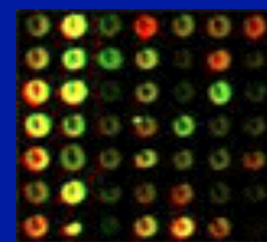
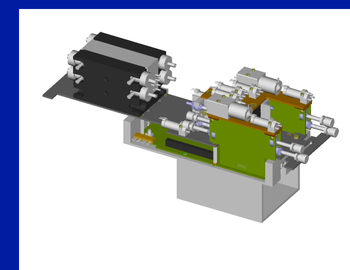
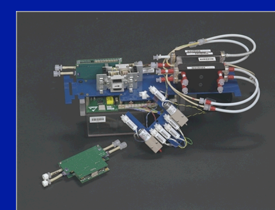
Typical Mars Design Reference Mission Scenario

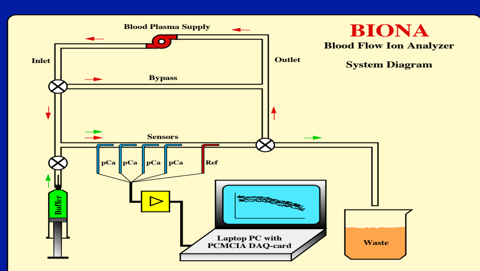


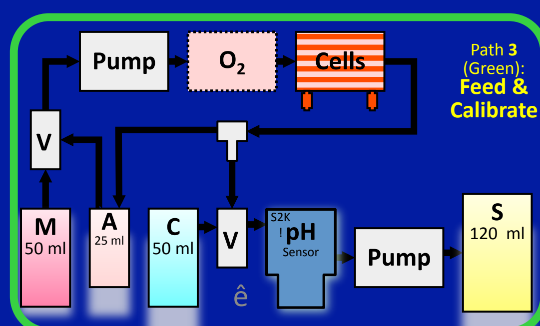
Space Synthetic Biology HW Elements

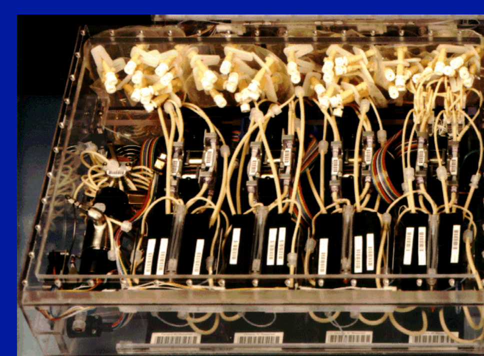
- Specimen Habitat
- Sample Handling
- Process Monitoring
- Process Control
- Bioreactor
- Mtg, Prod (scale up)
- Application/Utilization



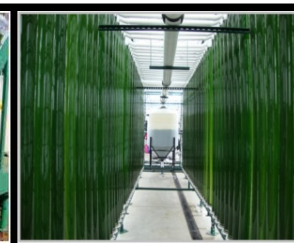






Synthetic Biology

for Sustaining Life In Space



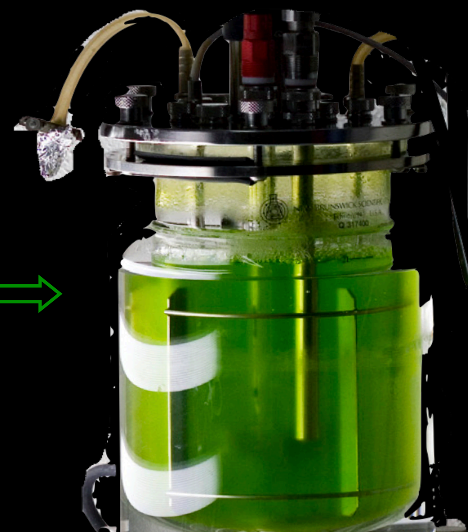
Biological In Situ *Resource Utilization (BISRU)*

Materials Utilized

•Terrestrial (transported upmass, waste, recycled materials

•Acquired in transit (*e.g.*, asteroid, repurposed upmass from other missions)

•Acquired *in situ*



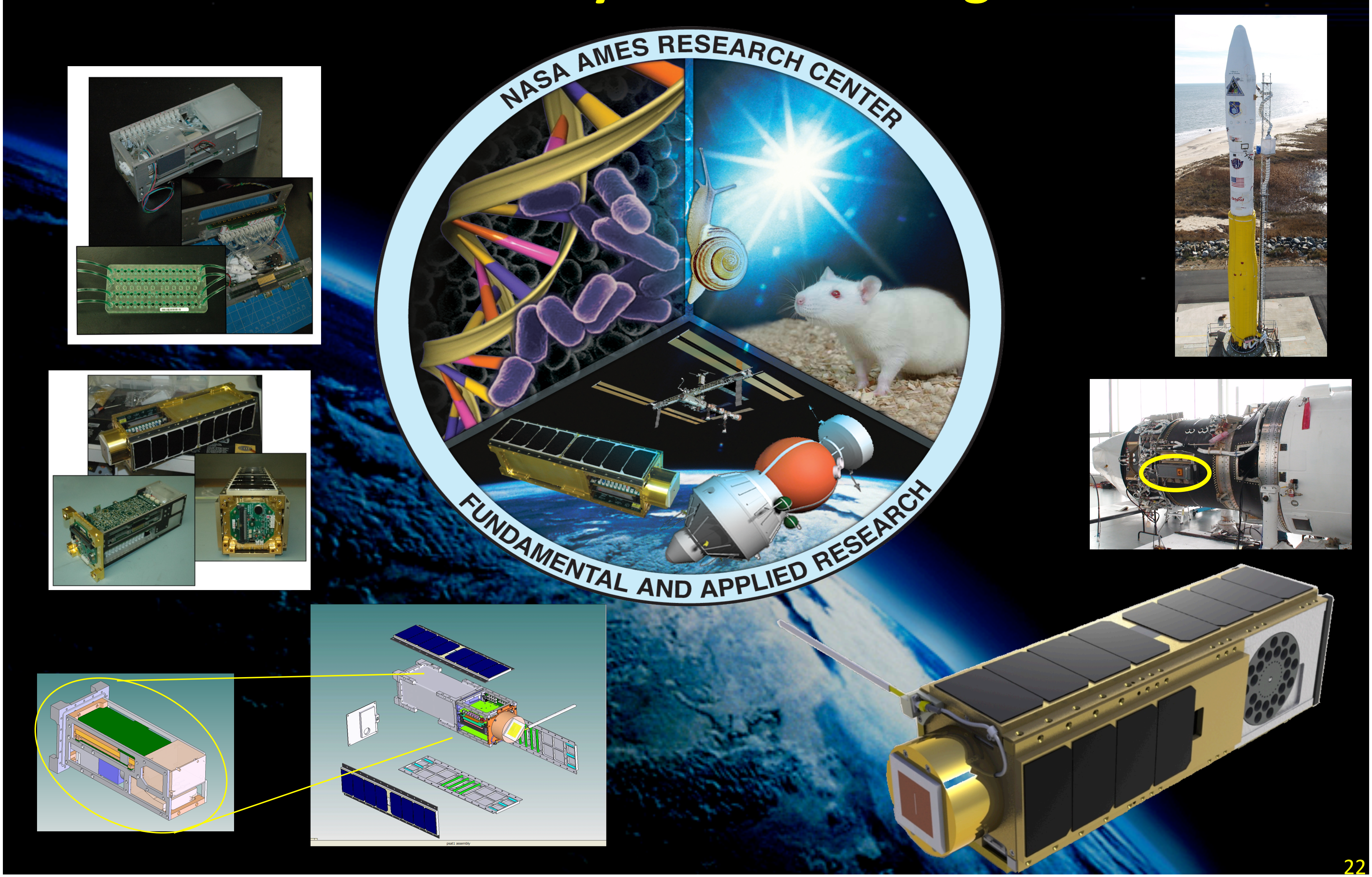
- Useful Products
- Foods, nutritional supplements & drugs
- Fuels
- Gasses
- Materials (polymers, fibers)
- Polymers
- Fibers
- Heat

Multi-purpose Synthetic Microbial Bioreactor

Potential advantages of synthetic bioprocessing over physical/chemical processing

- Facilitates closed loop life support and reduced upmass, reduced consumables, and reduced re-supply
- Reduced power required; potential for direct capture of solar energy by biological systems
- Provides on site flexibility in manufacturing with reprogrammable biological systems
- Facilitates *in situ* manufacturing and processing with reduced reliance on hazardous/toxic chemicals
- As compared to physical/chemical processing, Synthetic Biology has much greater potential for game-changing breakthroughs for sustaining life in space, as well as economically significant terrestrial applications

MicroSatellite Free Flyer Project:
in-situ Bioanalytical Technologies Thrust

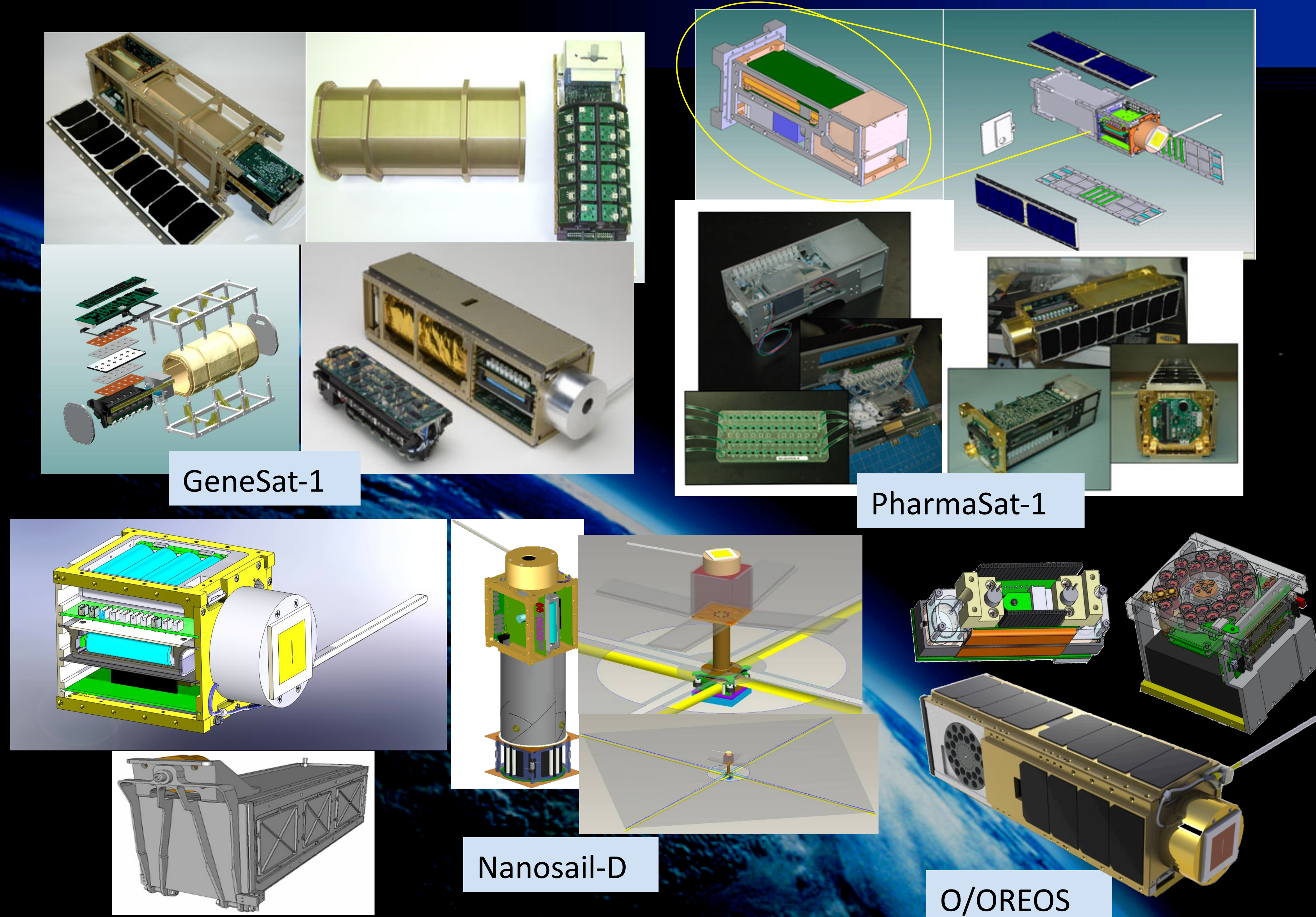


Free-Flyer Biotechnology Capabilities

- **Fully autonomous,** self-contained free-flyers
- Many possible configurations to address multiple research scenarios
  - Mix & match two or more 1.5-kg 10-cm^3 cube instruments
- **Mass: 4 – 50 kg** total spacecraft payload in µSat-FF configuration (3 – 75 L total volume)
  - 2 independent experiments/instruments w/ 7-kg satellite; at least 10 independent w/ 50-kg platform
  - Experiment/payload useable volume**:** 0.9 (55 in^3) – 50 liters
- **Accommodated** on most any launch vehicle due to small size, volume
- Many **orbital trajectories**: LEO, HEO, GEO, Lunar, *etc.*
- **Power consumption:** 4 – 50 W
- **Temperature:** 15 – 40 °C (4 °C with 30-50 kg version), <0.5 °C stability
- **Humidity:** 30 – 100%, active or passive control
- **Media:** liquid culture or solid/gel-supported growth; fluid exchange; bio/chemical challenges
- **Atmosphere:** 1 atm ± 10%; active O_2, CO_2 control; gas exchange
- ***In-situ,* real-time analysis;** autonomous data management & telemetry

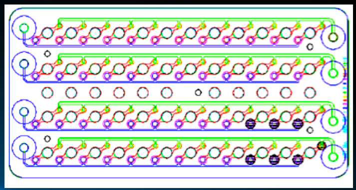
interactive w/ “timeout autonomy” or fully autonomous exp’tal. control as desired
- **Sample return** possible (future) with 50 kg versions

NASA-Ames Nanosatellite Projects

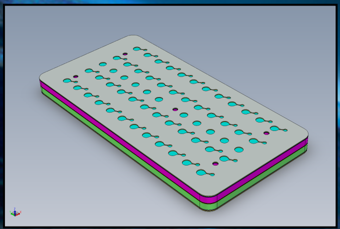


Pharmasat-1

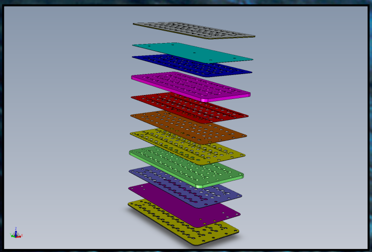
Microsatellite - Free Flyer Project



60-well BioFluidics card

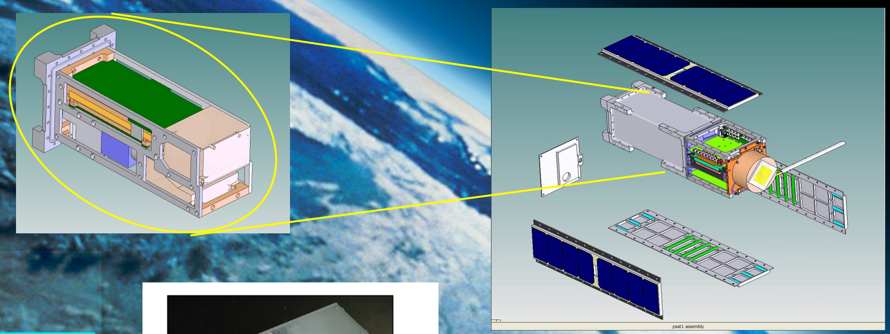


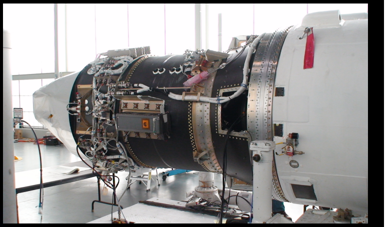
Card Laminate Assembly

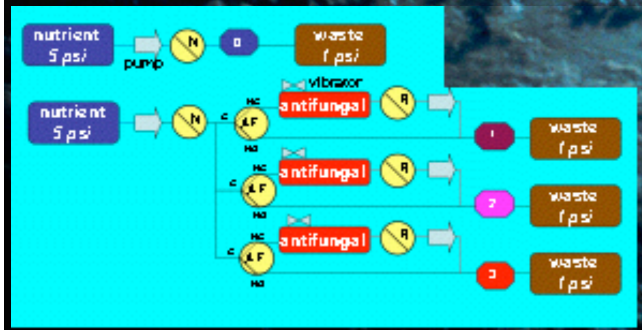


Card Assembly Exploded View

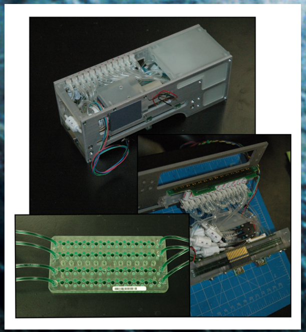
- Science goal: measure effects of antifungal agent on yeast
  - clinically accepted, well-controlled test protocols
- Manifested to launch w/ USAF Tacsat-3 1° spacecraft
  - Minotaur-1 launch vehicle, Wallops Flight facility; Jun08
- µSat Free Flyer: ESMD-funded, 4 mission, 5 year effort
  - develop nanosat-class autonomous space platforms & technologies
  - validate key biological responses indicative of space environmental conditions, human medical risks

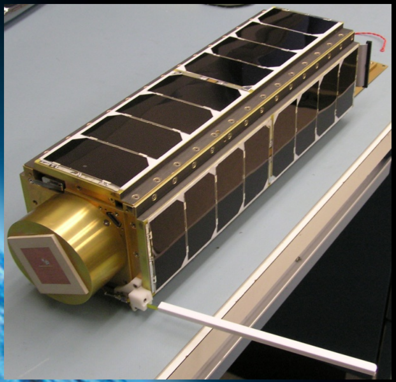




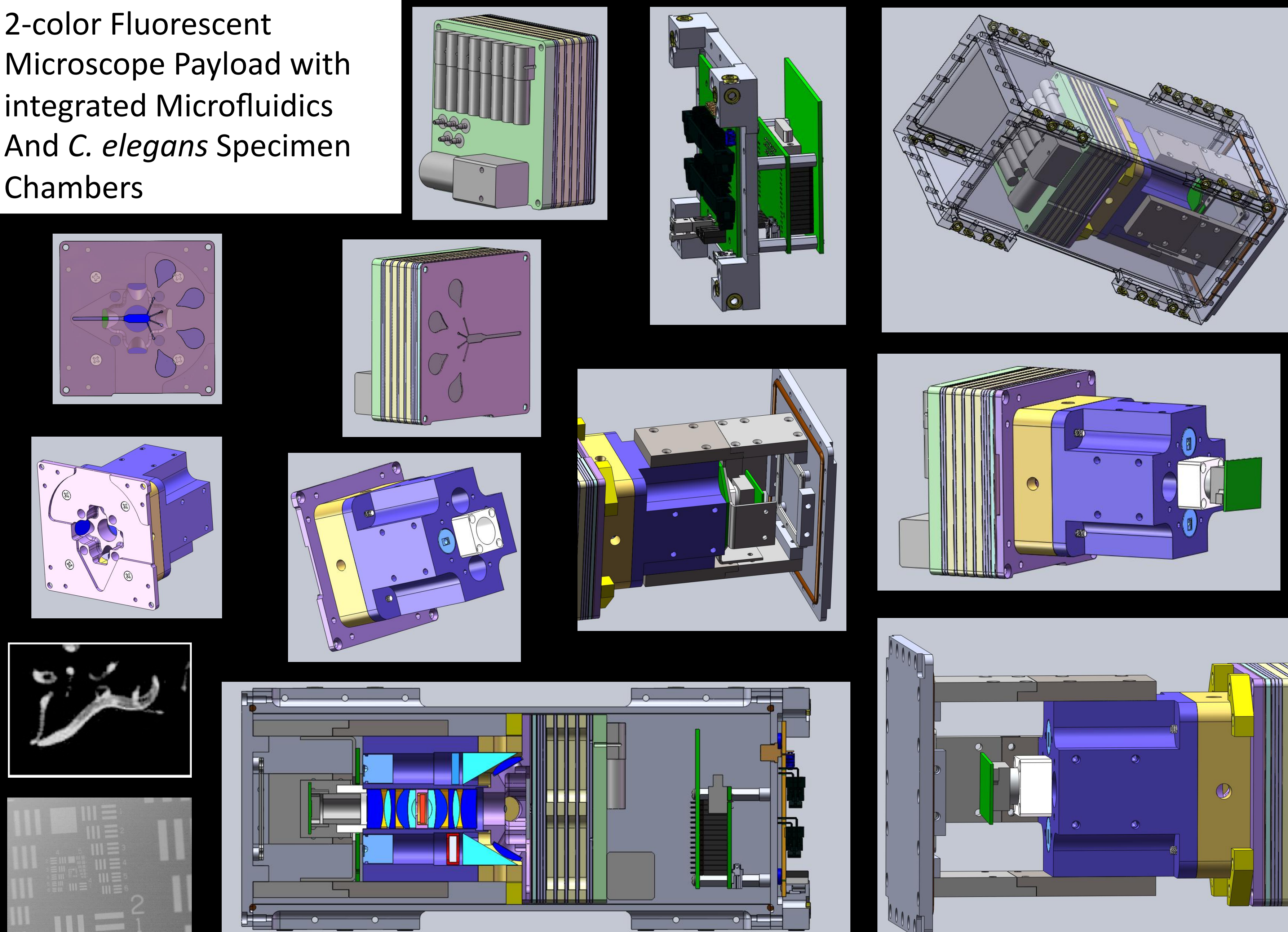


Fluidics/Sample Handling Block Diagram





MisST NanoSatellite
2-color Fluorescent
Microscope Payload with
integrated Microfluidics
And *C. elegans* Specimen
Chambers



µSat-FF Technologies & Applications
Present and Planned Capabilities

- **Development of technologies increases capabilities**
  - Advanced technology capabilities available to best support science community
  - Provides in-situ technologies to support a variety of model organisms/cells and materials
    - *E. coli**, yeast*, *B. subtilis**, *Hrr. chaoviatoris**, *C. elegans*, Drosophila, Arabidopsis, Cyanobacteria
    - Mammalian cells, tissues
    - PAHs, amino acids, biomarkers, etc. in thin-film format
- **Statistically significant analysis: µSat supports meaningful n size**
  - Enhanced well-plate specimen chambers (48* – 384 wells or more)
  - Additional high-density approaches: cytometry, microarrays, beads, bioreactors, etc.
- **Sample management & preparation for sophisticated experiments**
  - Thermal*, humidity*, atmospheric control* and gas sensing & exchange*
  - Fluid exchange*: addition of reagents,/nutrients*, agonists/antagonists, antifungals*, antibiotics, fixatives, etc.
  - Amplification (PCR, NASBA, etc.), lysis, separation, purification, labeling, filtration
- **Progressively sophisticated analytical/measurement capabilities**
  - in-situ optical density*; metabolism indicator-dye*; diffuse* or imaging fluorescence
  - multiple fluorescence tags, greater sensitivity; luminescence
  - autonomous protein crystal growth
  - FACS, cytometry/beads, and liquid arrays for multiplexed biological analysis
  - ELISA-like assays
  - Microarrays: DNA, RNA, protein, antibody; optical or electrochemical readout; 10s - 1000s

* Denotes current capabilities

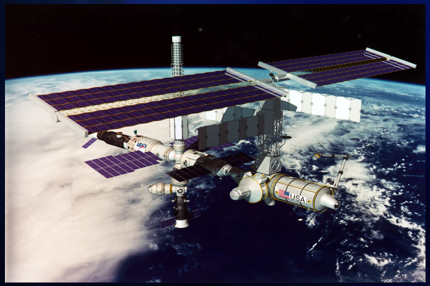
International Space Station

Multi-user EXPRESS Racks

Middeck locker scale instruments in various research disciplines such as biotechnology and plant research

Sub-rack class payloads and facilities

in



General constraints (roughly in the order most likely to be limiting, post-assembly complete)

- Upmass
- Downmass
- Crew time
- Thermal
- Facility throughput
- Power
- Data downlink

Expedition 14 crewmember Mike Lopez-Alegria conducting TROPI plant growth experiment in EMCS in EXPRESS Rack 3

European Space Agency Astronaut Thomas Reiter, Expedition 13 Flight Engineer, installing the EMCS facility into the EXPRESS Rack 3A.

Freezers and Incubators

Minus Eighty-degree Laboratory Freezer for ISS (MELFI)

- Provides thermal conditioning at +4$_o$C, -26$_o$C and -80$_o$C
- 1 unit currently on orbit
- 1 will launch in 2009, and 1 more in 2010

GLACIER Freezer

- + 4 $_o$C to -185 $_o$C

CGBA (Commercial Generic Bioprocessing Aparatus)

- -10$_o$C to +37 $_o$C.

ABRS (Advanced Biological Resarch System)

- Includes imaging of green fluorescent protein

EMCS (European Modular Cultivation System)

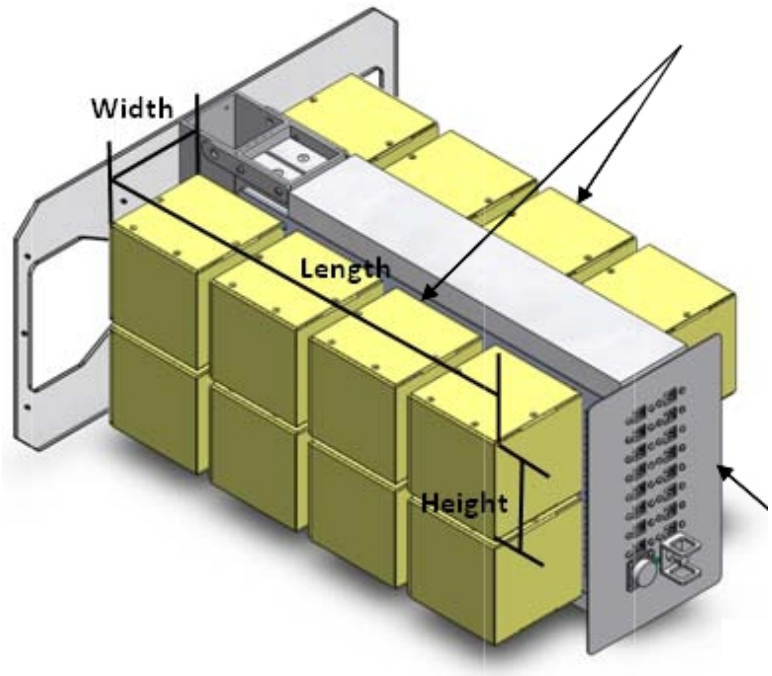
- Two centrifuges for plants and small animals spin from 0 to 2 G

Expedition 19 crewmember Michael Barratt inserts samples into the MELFI

General Laboratory Active Cryogenic ISS Experiment Refrigerator (GLACIER)

Centrifuges of EMCS

Commercial Generic Bioprocessing Apparatus (CGBA)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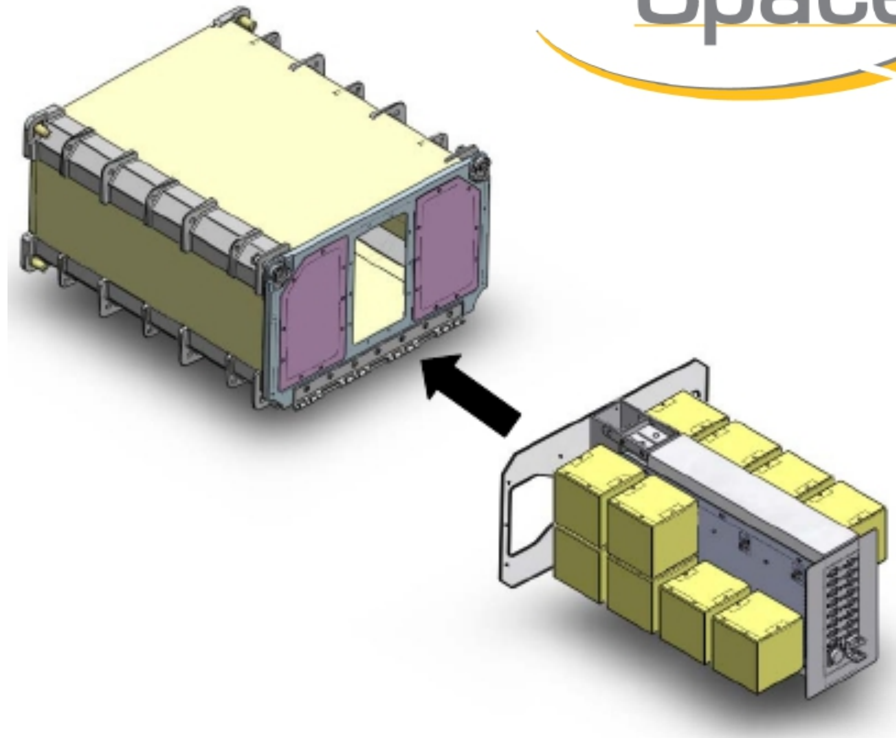
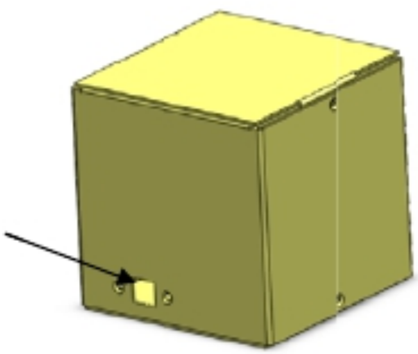
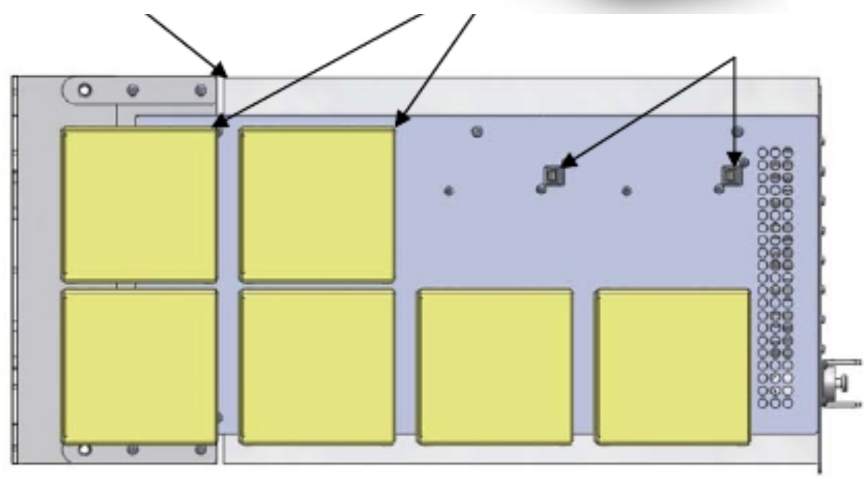
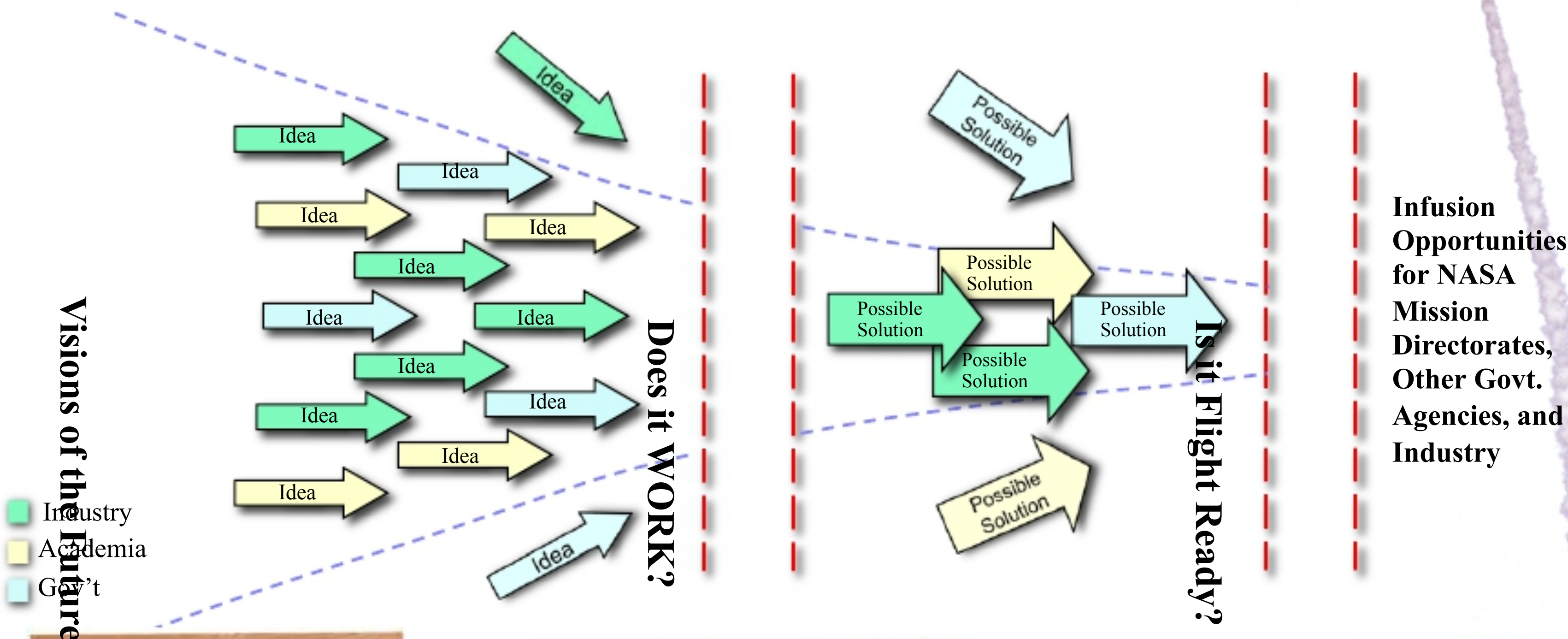






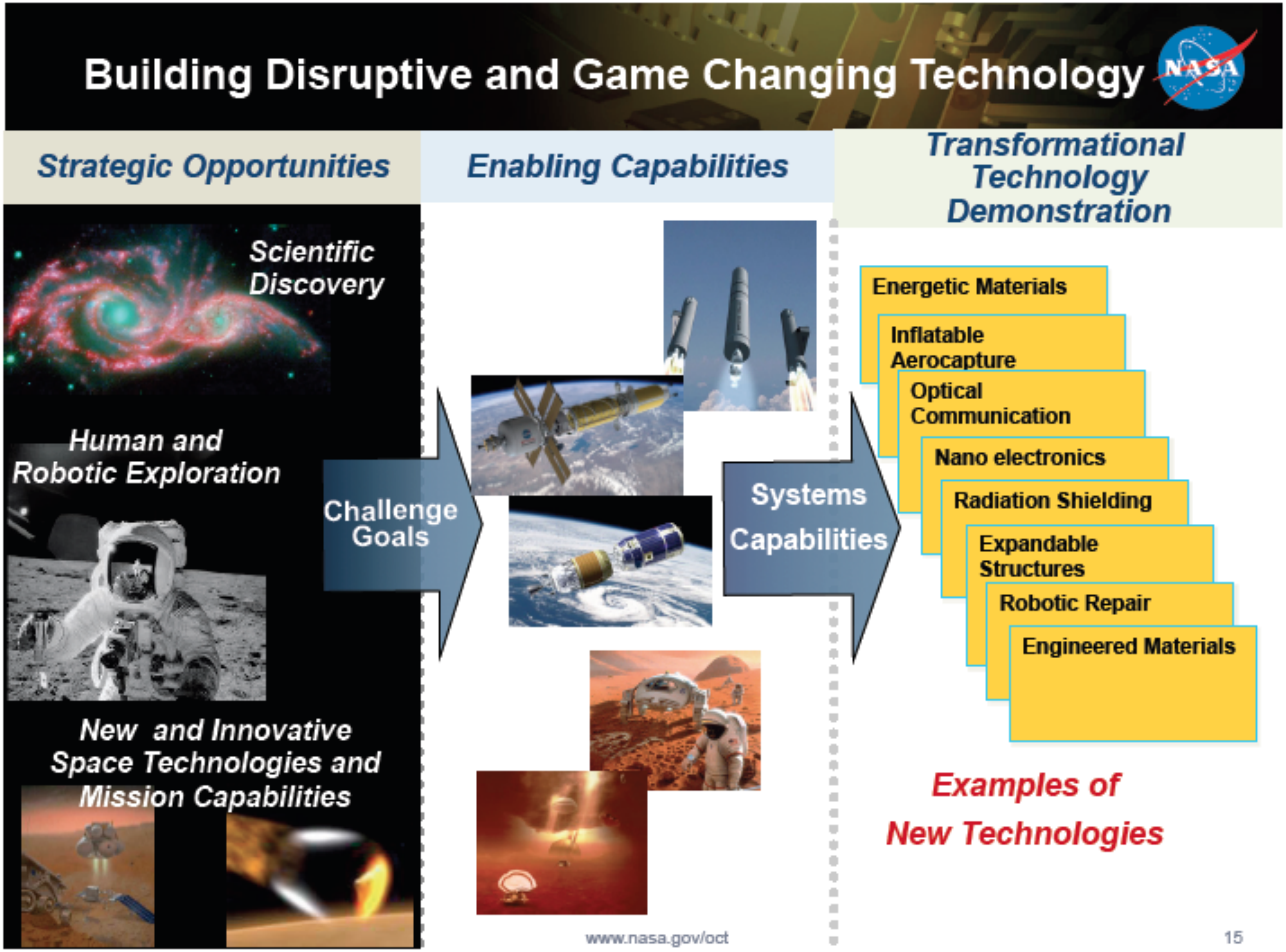
Space Technology Development Approach



Creative ideas regarding future NASA systems or solutions to national needs.

Prove feasibility of novel, early-stage ideas with potential to revolutionize a future NASA mission and/or fulfill national need.

Mature crosscutting capabilities that advance multiple future space missions to flight readiness status


Building Disruptive and Game Changing Technology
NASA
Strategic Opportunities
Enabling Capabilities
Transformational Technology Demonstration
Scientific Discovery
Human and Robotic Exploration
New and Innovative Space Technologies and Mission Capabilities
Challenge Goals
Systems Capabilities
Energetic Materials
Inflatable Aerocapture
Optical Communication
Nano electronics
Radiation Shielding
Expandable Structures
Robotic Repair
Engineered Materials
Examples of New Technologies
www.nasa.gov/oct
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A-STARS Technology Areas

1. LAUNCH PROPULSION SYSTEMS	6. HUMAN HEALTH, LIFE SUPPORT AND HABITATION SYSTEMS	11. MODELING, SIMULATION, INFORMATION TECHNOLOGY AND PROCESSING
2. IN-SPACE PROPULSION SYSTEMS	7. HUMAN EXPLORATION DESTINATION SYSTEMS	12. MATERIALS, STRUCTURAL AND MECHANICAL SYSTEMS, AND MANUFACTURING
3. SPACE POWER AND ENERGY STORAGE SYSTEMS	8. SCIENTIFIC INSTRUMENTS, OBSERVATORIES, AND SENSOR SYSTEMS	13. GROUND AND LAUNCH SYSTEMS PROCESSING
4. ROBOTICS, TELE-ROBOTICS, AND AUTONOMOUS SYSTEMS	9. ENTRY, DESCENT, AND LANDING SYSTEMS	14. THERMAL MANAGEMENT SYSTEMS
5. COMMUNICATION AND NAVIGATION SYSTEMS	10. NANOTECHNOLOGY	15. AERONAUTICS

Potential Synthetic Biology applications map to several OCT Roadmap Technology Areas:

Grand Challenges (DRAFT)

Make space part of our routine environment…

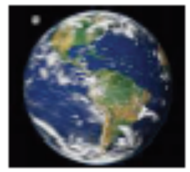
Achieve fast and economical space transportation

Enable in-space commercial/ marketable services

Improve spacecraft safety and protect astronaut health

Communications that enable virtual presence

Manage space as a natural resource…



Gain knowledge 0f climate change and natural disasters

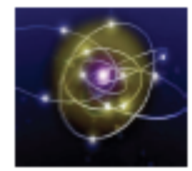
Provide economical energy on demand

Improve Knowledge of the near-earth environment

Invent the materials of exploration using in-situ manufacturing

Quests of the Future…

Exploit machine intelligence/robotic autonomy

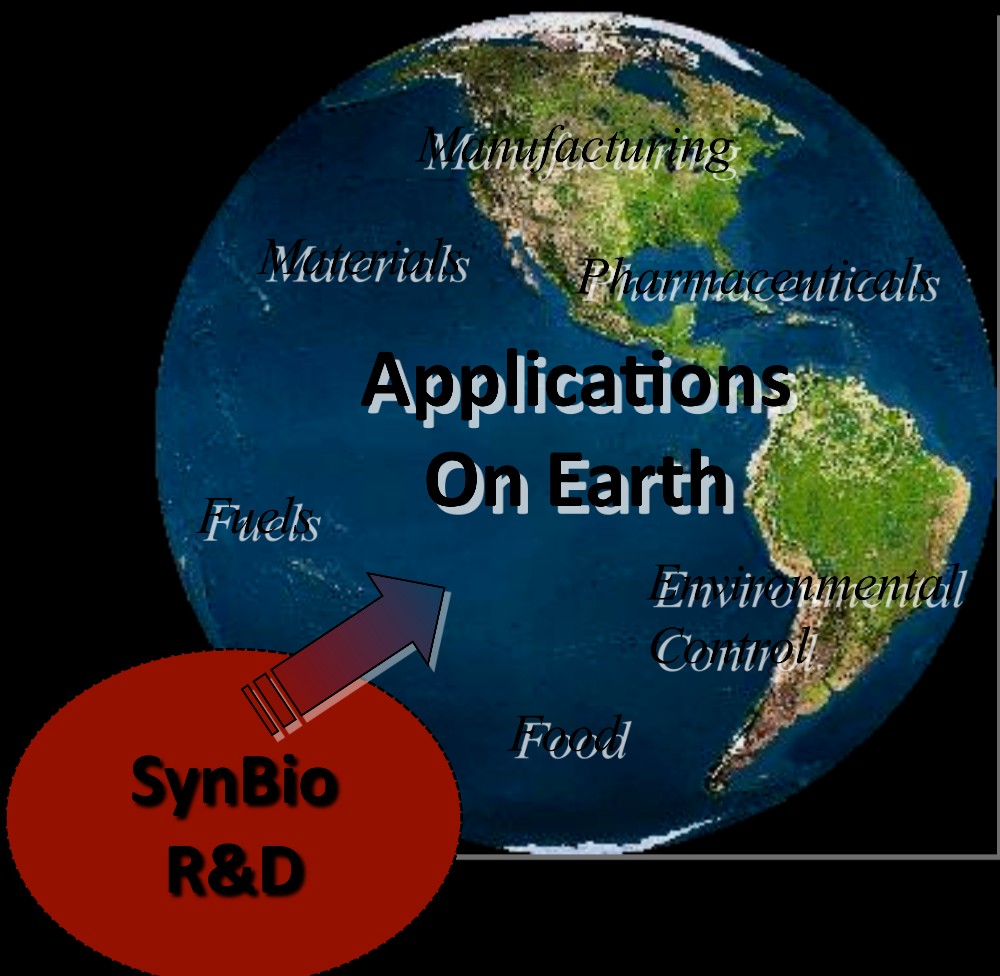


Understand laws of the universe

Discover life and earth–like worlds

Synthetic Biology is…

… An emerging, innovative, game-changing bioengineering discipline.



- *An engineering approach that seeks to construct new biological parts, devices and systems, as well as to re-design existing components to do useful work*
- *A new discipline that distinguishes itself from conventional genetic engineering with a heavy emphasis on developing foundational technologies that make the engineering of biology easier and more reliable.*
- *A rapidly growing area of biotechnology that can be employed to manipulate chemicals, fabricate materials and structures, produce energy and fuel, provide food, drugs, and nutrients, and maintain and enhance human health and our environment.*

Synthetic Biology

provides the foundation to revolutionize plant growth systems for space exploration and terrestrial utilization; for food, materials and air/water processing

Dwarf Tomato/Rice

Vitamin A Enriched Rice

Wavelength Experimentation

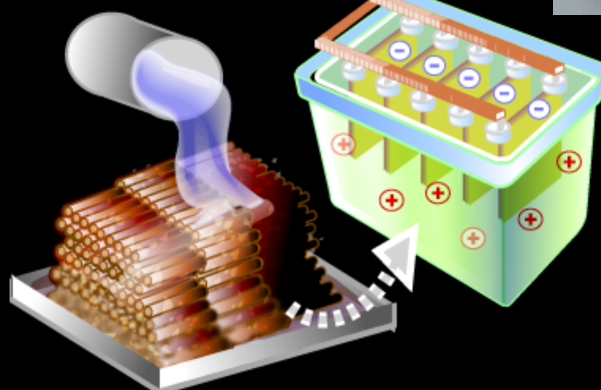
Super Plants
- Increased yield
- High harvest index
- Reduced volume
- Reduced nutrients/H_20

Enhanced Nutrition
- Increased vitamins
- Complete protein source
- Improved taste
- Longer storage capacity

Precision Metabolism
- >2x growth rates
- Precise wavelength use
- Radiation use/tolerance
- Disease resistance

Synthetic Biology

potential technology for biomining planets, moons and asteroids



- Extremophiles generate acid to dissolve metals in dilute ore
- Dissolved metal recovered via electroplating
- Produces ~ 25% of global copper supply

ENABLING and REVOLUTIONARY TECHNOLOGIES:

Prevailing Themes : BioCentric; Modular; Scaled; Nano; BioMimetic

- **Extensible Human***
- **NanoMimetics [nano-scale biomimetics]***
- **in-situ Planetary BioAnalytical Laboratories and Processing Plants**
- **Living Spacecraft (incl EVA and Surface facilities)**
- **Sustainable, Self Generating Planetary Biospheres**
- **Biological Transcommunications (local, distant)**
- **Molecular Engineering**
- **Responsive, Distributed Biointelligence**
- **Nano/meso-Scale Intelligent, Integrated Function Blocks ***

* Highlighted items have expanded descriptive information

Technology Emphasis: Extension of Human Presence to other Planets
"Extensible Human"

Elements

- Virtual BioCyborg
  [distributed, remote, intelligent, monitoring and control strategies and technologies]

- BioCollectives [distributed subsystems, payloads, and platforms]
  [local, autonomous, intelligence, human/biologics = components of system]

- Smart Skins. Garments, and Protective Materials (Human and Vehicular)

- Application-Specific, Smart, Localized Diagnosis and treatment
  •Genomics, Proteomics, Microbial

- in-situ Biological Health Management Technologies [BioAstronautics]
  - Local manufacturing/production of Drugs and reagents
  - Genomics / Proteomics
  - Biological and Biomedical Nanosensors, probes, and actuators
  - BioArtificial Fluids, Blood Substitutes [nanoblood]
  - Personal, ambulatory clinical laboratories
  - Bioartifical Materials and Structures for Prosthetic devices and assists

- Smart, Adaptive, Living Environments and Traveller Support Systems

- Transparent Technologies (non-invasive, unobtrusive, nano-scale)